

Site index for teak in Colombia

Danny A. Torres • Jorge I. del Valle • Guillermo Restrepo

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Abstract: Determination of site quality is a basic tool for proper selection of locations and species, in management of forest plantations. Throughout the Caribbean studies of site quality are few and are hampered by statistical limitations, inappropriate growth models, and limited data. We fitted growth curves for dominant height to evaluate and classify site quality of teak (*Tectona grandis*) plantations by using data from 44 permanent sample plots established since 1990 in 3–22 years old teak plantations in the Colombian Caribbean region. We used Korf's and von Bertalanffy's models to fit curves as non-linear effects models. Both models, with a single random parameter, were considered as adequate for dominant height growth modelling, but Korf's model was superior. The resulting curves were anamorphic and closely reflected high variability in site quality. Five site classes were clarified: at a base age of 12 years old, teak reached a mean dominant height of 24.8 m on the best sites, 9.8 m in the worst sites, and in the averages sites, 15.8–18.8 m. Using this model, we identified the best and the worst sites for teak plantations in the Caribbean region. This model proved a useful tool, not only for site quality evaluation, but also for improved teak plantation planning and management.

Keywords: *Tectona grandis*; site index; growth modelling; permanent sample plots; Colombia

Introduction


Forest site quality refers to the sum of factors that affect the productive capacity of forests. Factors can be classified into three

groups: climatic, biotic, and edaphic (Carmean 1979). Site quality is defined as the potential production of timber in a particular site for a particular species or a specified forest type (Clutter et al. 1983). The most commonly used method is direct sampling of the mean height of dominant trees in a stand, because in even-aged stands it is little affected by stand density or thinning (Clutter et al. 1983). Site quality correlates closely with timber production in terms of volume or biomass (Clutter et al. 1983). According to this method, site index (*SI*) is defined as a measure of site quality, based on the mean height of dominant and co-dominant trees of arbitrarily sampled age classes (Carmean 1979). The curves of *SI* that result from classifying and categorizing height growth curves can be fitted in several ways, but always through height-age coordinate pairs.

Previous studies used the *SI* method for determining site quality in teak (*Tectona grandis* L.f.) plantations, but most used data from temporary plots (Nunifu and Murchinson 1999; Henao 1982; Keogh 1981 and 1982; Bermejo et al. 2004). Quite often, when Permanent Sampling Plots (PSPs) were used, the possible existence of polymorphism was not corroborated (Vaides et al. 2004; Upadhyay et al. 2005; Jerez-Rico et al. 2011). Most researchers used the guide curve method (or proportional curves method), which generates anamorphic curves and uses the non-versatile Schumacher's model (Nunifu and Murchinson 1999; Henao 1982; Keogh 1982; Bermejo et al. 2004; Vaides et al. 2004; Jerez-Rico et al. 2011). Although this method has received little attention, it is important because the presence of polymorphic patterns can indicate two things. First, the height growth of a species is sensitive to silvicultural treatments. Second, silvicultural treatments are often continued after trees have reached heights where the treatments no longer have an impact. Therefore, one species may show both patterns of growth. Upadhyay et al. (2005) used both the guide curve and the difference equation method with PSPs to develop site index curves in teak plantations in India using the Hossfeld IV growth model. They found the polymorphic difference equation method to be superior. From research on teak management regimes, it can be inferred that growth in height is independent of stand density. A 15 year stand of teak in Nigeria received three treatments: unthinned (2,200 trees·ha⁻¹), thinned to 760 trees·ha⁻¹, and thinned to 395 trees·ha⁻¹ (Lowe 1976). When the stand was 20

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Danny A. Torres
Office National de Forêts International, 2, av. de Saint-Mandé, 75 570
Paris Cedex 12, France. E-mail: danny.torres@onf.fr

Jorge I. del Valle 
Universidad Nacional de Colombia sede Medellín, Apartado Aéreo 568,
Medellín, Colombia. E-mail: jidvalle@unal.edu.co

Guillermo Restrepo
Independent consultant, E-mail: grestrepo@une.net.co

Responsible editor: Yu Lei

years old, the fastest tree growth was unrelated to the treatments. Vincent et al. (2000) carried out a thinning experiment in Barinas, Venezuela. In a 13-year-old teak plantation, they established several spacing regimes from $2\text{ m} \times 2\text{ m}$ to $4\text{ m} \times 4\text{ m}$. At 18.7 years, there was no relationship between dominant tree height and thinning regime. Jerez-Rico et al. (2011), working in the western plains of Venezuela, examined data from permanent and temporary plots of teak that included more than 30 years of measurements. Initial spacing varied from $2\text{ m} \times 2\text{ m}$ to $4\text{ m} \times 4\text{ m}$, and density at sampling ranged from 200 to 2,400 trees $\cdot\text{ ha}^{-1}$. They found that dominant height was little affected by tree density. On the Peninsula of Nicoya, Costa Rica, Chaves et al. (2003) established a thinning experiment in a seven year old teak plantation with the following treatments: $15\text{ m}^2 \cdot\text{ ha}^{-1}$, $17\text{ m}^2 \cdot\text{ ha}^{-1}$, $19\text{ m}^2 \cdot\text{ ha}^{-1}$, $21\text{ m}^2 \cdot\text{ ha}^{-1}$, and $25\text{ m}^2 \cdot\text{ ha}^{-1}$. The experiment continued until trees reached 20 years in age. Growth in the dominant tree height was not affected by treatments. Jerez-Rico et al. (2011) used mixed models to study the growth of teak.

The first approaches in Colombia for studying the growth of teak were from Echeverri (1968) and Rodríguez (1968), but they did not attempt to develop site index curves. Henao (1982), in a plantation of the Department of Córdoba and on the basis of average tree height from temporary sample plots, found no significant quality differences between sites. A recent and continuing study of *SI* is the site classification chart for the Caribbean, Central America, Venezuela, and Colombia (Keogh 1982). In our study, the data for Colombia were taken from the Venegas report in 1977 “Reply to teak questionnaire”, performed by the FAO COL/74/005 Project. In recent decades, various timber companies planted teak not only in Colombia but also in other Caribbean countries. However, the foresters from the Caribbean use few teak site index studies to properly manage this species. In Colombia, we used the result of Keogh (1982) that was based on limited data and used outdated methods. Our study aims to use modern statistical techniques and widely accepted growth models to develop a family of site index curves for teak from the

Colombian Caribbean. Our results are applicable to all Caribbean teak plantations.

Materials and methods

Study area

In Colombia, and particularly in the Córdoba Department, Colombian Caribbean region, teak has been planted for over 70 years (Rodríguez 1968; Echeverri 1968; Keogh 1981). According to the Holdridge (1982) classification scheme, the area falls under the lowlands monsoonal association of the humid tropical forest life zone. The rainfall regime is unimodal and at the most representative weather station (IGAC 1978) averages 2,479 mm/yr. Approximately, 30% of rain falls between August and September and less than 60 mm per month falls during January and February. The annual mean temperature is 27°C , with daily amplitude of 10°C . Relative humidity varies from 75% to 84%. All teak plantations are on colluvial-alluvial soils with fluvial-lacustrine deposits used for livestock grazing before the plantations were established (IGAC 1989).

Data source

In 1990, 20 Permanent Sampling Plots (PSPs) were established in the teak plantations of the Córdoba Department, and the number of PSPs was increased in subsequent years (Fig. 1). The age of the PSPs ranged from 3 to 22 years. In 2011, there were 44 PSPs. The PSPs had two plot sizes. The plot size of 23 PSPs was 600 m^2 (i.e.: $30\text{ m} \times 20\text{ m}$) and the plot size of the remaining 21 PSPs was $1,000\text{ m}^2$ (i.e.: $40\text{ m} \times 25\text{ m}$). Diameters at breast height (1.3 m above ground) and dominant height (mean tree height of the 100 tallest trees per hectare) were measured annually. Dominant height was used as an indicator variable for site quality.

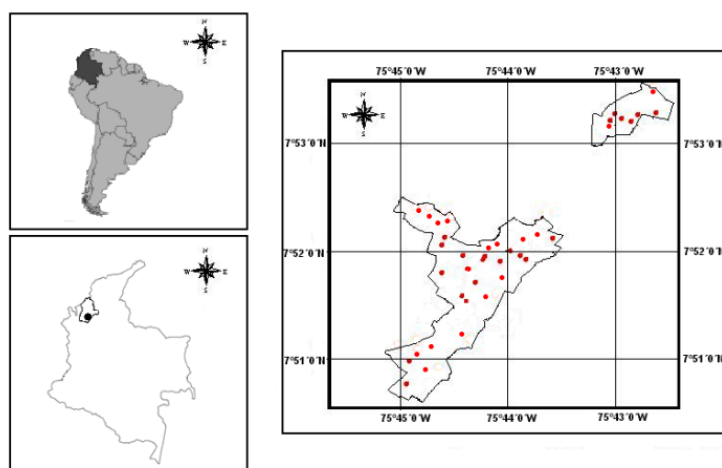


Fig. 1 Study area. The dots show the location of the permanent plots.

All the PSPs were subjected to the same management regime. The plantation stocking density was 1,600 seedlings $\cdot\text{ ha}^{-1}$ (i.e., a

spacing of $2.5\text{ m} \times 2.5\text{ m}$), manual weeding was carried out three times during the first two years and once each year in subsequent

years until the end of the rotation. Pruning was carried out in years five and nine. Basal area was maintained close to 26 m² · ha⁻¹ by two thinnings between years 7–9 and 12–13.

Modelling

In order to fit mean dominant height growth functions, two models used in silviculture were evaluated: von Bertalanffy (or Chapman-Richards's, Eq. 1), and Korf (Eq. 2) (Kiviste et al. 2002).

$$Hd = A[1 - \exp(-\beta_1 t)]^{\beta_2} \quad (1)$$

$$Hd = A \exp\left(-\frac{\beta_1}{t^{\beta_2}}\right) \quad (2)$$

where, Hd is the dominant height (m), A is the asymptote (m) or maximum value reached by Hd , β_1 and β_2 are the unknown parameters, t is the age (year) corresponding to each Hd , and $\exp()$ is the exponential operator (Euler's constant).

As all data were collected in PSPs, this is a typical case of repeated measures over time (or longitudinal data) without independence among intra-plot measurements. Therefore, there can be serious problems in autocorrelation of errors, when the parameters are estimated by conventional least squares methods (linear or non-linear). Besides the problem of autocorrelation, growth and yield data from permanent plots usually exhibit heteroscedasticity (Gregoire 1987).

A non-linear mixed-effect model was used to derive reliable estimators of the growth model parameters. It enabled modelling of the intra-individual covariance structure, assuming that (usually one or two) individual-independent, small-dimension latent random-effects vectors existed in the model (SAS 1999). To apply this method, a re-parameterization of models (Eq. 1 and Eq. 2) was made (Fang and Bailey 2001), by changing the value of the asymptote A by an unknown parameter β_1 . The value of β_1 corresponds to the expected value of Hd when $t = t_0$. Then Eq. 1 and Eq. 2 can be represented in the following way:

$$\overline{Hd} = \beta_1 \left[\frac{1 - \exp(-\beta_2 t)}{1 - \exp(-\beta_2 t_0)} \right]^{\beta_3} \quad (3)$$

$$\overline{Hd} = \beta_1 \exp\left[\beta_2 \left(\frac{1}{t^{\beta_3}} - \frac{1}{t_0^{\beta_3}}\right)\right] \quad (4)$$

Where, $\beta_1 = \varphi + b$, unknown parameter corresponding to the SI value for a base age of $t_0 = 12$ years. A mixed parameter is considered fixed for both models (i.e., it has a fixed (φ) and a random (b) part), and β_2 and β_3 are unknown parameters.

Using this model, polymorphic and anamorphic growth curves

can be obtained. Several authors (Cieszewski and Bella 1989; Cieszewski and Bailey 2000; Fang and Bailey 2001) examined the properties of these models. Eq. 3 and Eq. 4 are fitted following a single random effect in the β_1 parameter, and each model is evaluated considering three variance structures: constant variance, variance as a potential function of the mean, and variance as an exponential function of the mean, for a total of six models. Each model is evaluated in terms of the statistical significance of the parameters, and is compared through both the Akaike information criterion (AIC) and the Bayes information criterion (BIC). The selected model undergoes a diagnostic of residuals, as proposed by Fang and Bailey (2001). This modelling phase was performed using the NLM Procedure in SAS System for Windows V. 8 (SAS 1999).

Site classes

After selecting the best model, we estimated the SI for the average site (random parameter = 0). We then identified sites above or below the average by considering the variation of the random parameter. We then ranked sites according to the intervals of four standard deviations (± 2 standard deviations around the average site).

To place each plot in its corresponding site class, the SI for each plot measurement was estimated (by isolating the β_1 parameter of the selected model) and the value was placed in the corresponding category. This procedure is also useful to evaluate the goodness of fit, because all of the measurements from the same plot should be placed in the same site class. Another way in which site classes can be assigned is by plotting on a coordinate diagram the curves that outline each site class, and then plotting the estimations of Hd for each plot.

Results

Exploratory analysis of the database

Scatter plots of the dominant height for some of the PSPs are depicted in Fig. 2. Not all 44 PSPs are shown in Fig. 2, because many PSPs overlapped, and it was difficult to correctly interpret the scattering. However, the scatter plots show high variability in the growth of teak in the study area, reaching dominant heights at 16 years ranging from 11–27 m. It is important to highlight the heteroscedastic nature of the scattered plots in Fig. 2 because variability increased with age. In most but not all cases, dominant trees sampled in successive sampling periods were the same. Therefore, there was temporal autocorrelation in the series of dominant height, another problem for the regression analysis.

Modelling

The parameters of Eq. 3 and 4, evaluated on each one of the variance structures, were statistically significant with a confidence level of 95% (Table 1). The values of the two selection criteria for each model are shown in Table 1 under the three

variance structures.

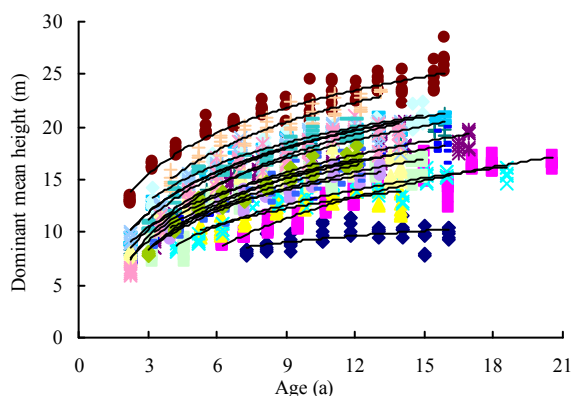


Fig. 2 Mean dominant height versus age for 14 out of 20 PSPs measured nine or more times. Points with equal shape belong to the same plot

Though all of the models were statistically acceptable, the models with variance as an exponential function of the mean were better (3.3 and 4.3). Of two values, Korf's model (4.3) was the most appropriate, because its Bayesian's criterion was slightly lower than for von Bertalanffy's model (Table 1) with the variance of Hd as an exponential function of its mean, and a base age of 12 years (Eq. 5). There were no evident autocorrelation (Fig. 3), heteroscedasticity, or lack of fitness problems in relation to observation order (observation number or the predicted values). The lack of outliers in Fig. 3 suggests a normal error distribution. The statistical results show that the non-linear mixed-effect model corrected the residual problems inherent in longitudinal data. It should be noted that von Bertalanffy's model also shows similar characteristics of residuals (Fig. 3)

$$\bar{Hd} = 17.28 \exp \left[-1.96 \left(\frac{1}{t^{0.65}} - \frac{1}{12^{0.65}} \right) \right] \quad (5)$$

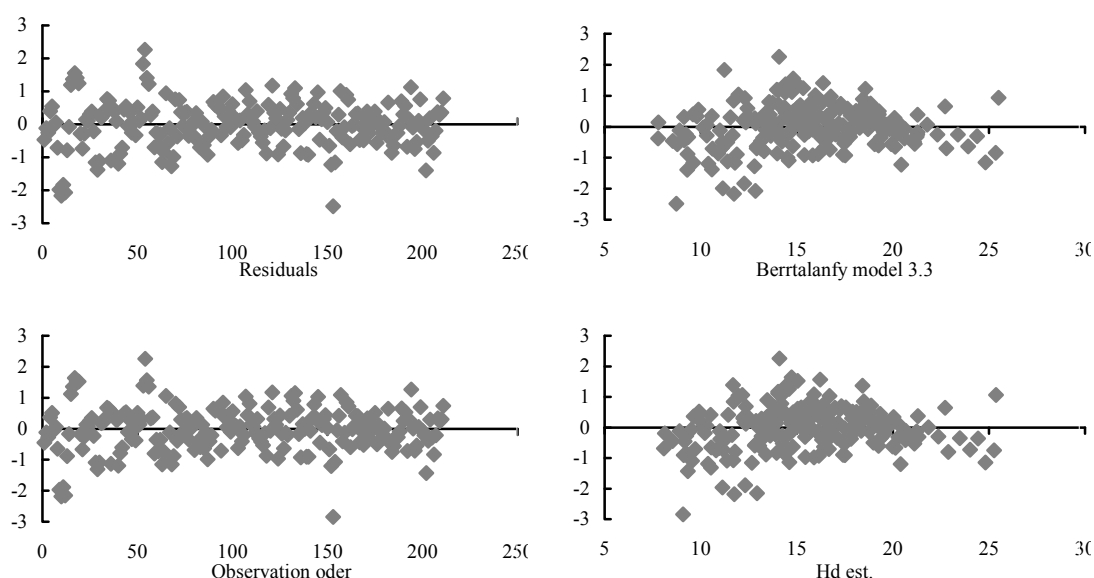


Fig. 3 Residuals of the dominant height (Hd) as a function of both, observation order and estimated value ($Hd\ est.$)

Table 1. Results of the information criteria: Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC)^a.

Model	3 (von Bertalanffy)			4 (Korf)		
	3.1	3.2	3.3	4.1	4.2	4.3
Variance structure	Constant	Potential	Exponential	Constant	Potential	Exponential
AIC ^a	586.5	583.4	579.1	578.5	575.2	570.7
BIC ^a	591.2	588.1	583.8	583.3	579.9	475.4

^a The lower the value, the better the model. von Bertalanffy's and Korf's growth models were similar and statistically acceptable. Korf's model (4.3) was the most appropriate because it achieved the minimum Bayesian criteria.

Eq. 4 can be also written with site SI as a dependent variable of age (t) and Hd . This is accomplished by isolating the parameter β_1 , which, as mentioned above, corresponds to SI at base age of 12

years, and by replacing the values of the other parameters presented on Eq. 5. In this way, Eq. 6 can be obtained.

$$SI = \frac{Hd}{\exp\left[-1.96\left(\frac{1}{t^{0.65}} - \frac{1}{12^{0.65}}\right)\right]} \quad (6)$$

Site index classes

When intervals of ± 2 standard deviations are considered around the average site, five intervals are needed to cover the complete range of Hd . SI limits for each category are shown in Table 2 and the corresponding SI curves are shown in Fig. 4. There was great variability in the site indexes. For trees twelve years old, the site index curves covered plantations from approximately 9.8 m up to 24.7 m of dominant height.

Table 2. Limiting values for site index classes for teak in Colombia separated by intervals of ± 2 standard deviations around the average site

Site index classes	SI		Number of PSPs
	Lower limit (m)	Upper limit (m)	
I	21.7677	24.7617	4
II	18.7737	21.7677	12
III	15.7797	18.7737	17
IV	12.7857	15.7797	8
V	9.7917	12.7857	3

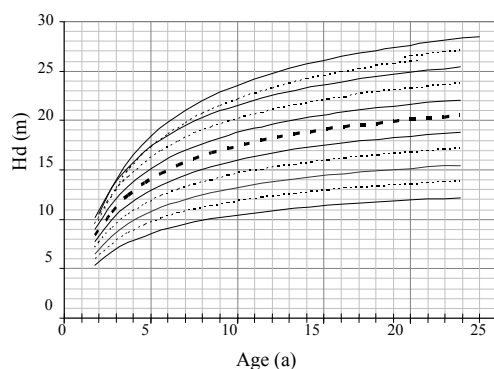


Fig. 4 Site index curves for teak (12 years base age). Dotted lines are the SI curves and continuous lines are limits of each SI classes (I to V)

Discussion

Estimated values of SI were similar for different ages of the same PSP. Fig. 2 and Fig. 4 show high variability of SI s. Dominant height followed an anamorphic curve, and this was confirmed by the satisfactory fit of this kind of model. As discussed in the introduction, there is abundant evidence that height increase in teak is poorly related with stand density. This result differed from the findings of Fang and Bailey (2001), who researched slash pine, and considered all parameters as mixed due to the high variability of silvicultural treatments. They found height increments that fit

polymorphic curves. In our study, only a random parameter was necessary due to the anamorphic nature of the curves.

Height growth of the dominant teak trees was well represented by Korf's model as modified (Fang and Bailey 2001). Moreover, this model eliminated the incompatibility problem between tree height growth and SI described by Curtis et al. (1973). Another advantage of the model is that it does not vary with changes in base age (Bailey and Clutter 1974). This means that the SI predicted by the model is independent of the reference age (Fang and Bailey 2001).

In our plantations, 39% of the PSPs were categorized as the average site class III. The proportion of PSPs with SI classes above the average (Classes I and II) was 35%, while 26% of PSPs were below the average site class (Classes IV and V). The shape of SI curves resembled those of Henao (1982) (Fig. 5a). In the value range, they resemble more those of Keogh (1982) (Fig. 5b). This last result is interesting, because in the Colombian Caribbean all of the SI classes reported by Keogh (1982) for Central America, the Caribbean, Venezuela, and Colombia were represented. The site ranges, presented by Miller (1969) for Trinidad, by Bermejo et al. (2004) and Pérez and Kanninen (2005) for Costa Rica, by Jerez-Rico et al. (2011) for Venezuela and by Vaides et al. (2004) for Guatemala, also fell within the SI curves developed in this study. However, top height in Ghana at 12 years varied between 8 m on the poorest sites and 15 m on the best sites (Nunifu and Murchinson 1999), figures substantially lower than in the Caribbean.

Both Henao (1982) and Keogh (1982) in Colombia used Schumacher's model (Schumacher 1939), which is a simplification of Korf's model (Eq. 2) because the β_2 exponent of t is equal to one. This simplification reduces the versatility of Korf's model, compelling the function to reach a change in concavity (Point of inflexion in $t = \beta_1/2$, and $Hd = 0.135A$) at exactly 13.5% of the asymptotic value without relation with the recognized explosive initial height growth of teak. This is why the work of Henao and Keogh underestimated the initial growth and the SI of teak (Fig. 5a and 5b).

Upadhyay et al. (2005) used the Hosfeldt IV model (Kiviste et al. 2002) for top height SI curves at 25 years base age for teak in India according to 150 PSPs established in all teak plantations in the country, representing the top height from 4 to 93 years. Similar sites were estimated by these curves at their base age, an approach different to that used in this study. At 25 years the poorest sites were the same as in our study ($Hd = 11$ m) and the best sites were similar (29 m in our study versus 28 m in the Indian study). However, the slope of SI curves in our study began higher and then declined, while the SI curves of the Indian study maintain a more stable slope. Both mean SI curves intersected at $t \approx 32$ years. Therefore, after this year the Indian SI curves predicted higher top height than dominant height as found in our study. The opposite occurred before 32 years of age (Fig. 6). In spite of the large database in the Indian study, they did not measure, but rather estimated the top height of the trees by using an allometric relationship between the quadratic mean diameter of ten trees with larger diameter per plot versus the average height of these trees (Upadhyay et al. 2005). Because trees with the largest diameter

are not necessarily the tallest, this procedure tends to overestimate the top height of the older trees with larger diameters. This is due to the fact that old trees continue growing in diameter but do not necessarily grow more in height. The same pattern results when *SI* curves of Upadhyay et al. (2005) are compared with many of the published teak *SI* curves (Miller 1969; Henao 1982; Keogh 1982; Malende and Temu 1990; Nunifu and Murchison 1999; Bermejo et al. 2004; Mora and Meza 2004; Pérez and Kanninen 2005; Jerez-Rico et al. 2011).

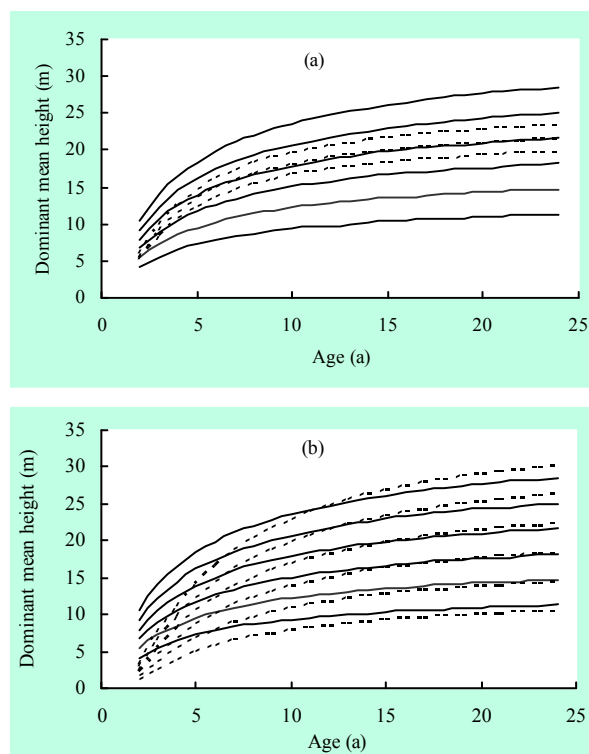


Fig. 5 Comparison of *SI* curves in the study (solid lines) with (a) Henao (1982) and (b) Keogh (1980) *SI* curves (dotted lines)

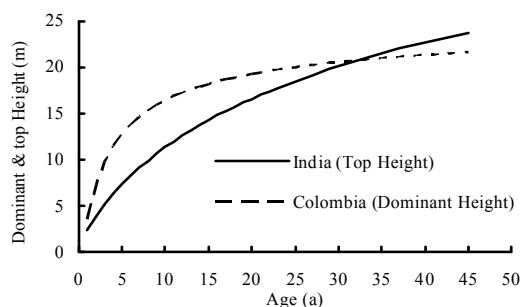


Fig. 6 Comparison between the mean *SI* curve in the study (thick dark line) and Upadhyay et al. (2005) mean *SI* curve (thin clear line)

Growth of dominant tree height for teak in Colombia reflects site quality. The array of sites yields an anamorphic system of curves, allowing site classification for this species. In the Co-

lombian Caribbean region, most previously reported ranges of *SI* for teak throughout the tropics are represented.

Potential users of this study for the site index classes of a teak plantation must use the same criterion for dominant height as used in this research for modelling *SI* curves. In this way, with the knowledge of the dominant height (i.e. the mean height of 100 tallest trees per hectare (*Hd*) or its estimation through permanent or temporary sample plots) and the corresponding age, the coordinate pair (*Hd*, age) can be plotted as in Fig. 4. Thus, the site class to which the measures correspond can be identified. In order to calculate the *SI*, that is, the exact value of *Hd* expected at 12 years, Eq. 6 must be used. This value can be categorized afterwards, when confronted with the limit values of each *SI* class presented in Table 2.

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References

- Bailey RL, Clutter JL. 1974. Base-age invariant polymorphic site curves. *Forest Science*, **20**(2): 155–159.
- Bermejo I, Cañellas I, Miguel AS. 2004. Growth and yield models for teak plantations in Costa Rica. *Forest Ecology and Management*, **189**: 97–110.
- Carmean WH. 1979. Site index comparisons among northern hardwoods in northern Wisconsin and Upper Michigan. Research Paper NC-169. St. Paul, MN: U.S. Dept. of Agriculture, Forest Service, North Central Forest Experiment Station.
- Chaves ES, Fonseca WG. 2003. Ensayos de aclareo y crecimiento en plantaciones de teca (*Tectona grandis* L.f.) en la Península de Nicoya, Costa Rica. Instituto de Investigación y Servicios Forestales (INISEFOR). Universidad Nacional, Heredia, Costa Rica.
- Cieszewski CJ, Bella IE. 1989. Polymorphic height and site index curves for lodge pole pine in Alberta. *Canadian Journal of Forest Research*, **19**(9): 1151–1160.
- Cieszewski CJ, Bailey RL. 2000. Generalized algebraic difference approach: Theory based derivation of dynamic site equations with polymorphism and variable asymptotes. *Forest Science*, **46**(1): 116–126.
- Clutter JL, Fortson JC, Pienaar LV, Brister GH, Bailey RL. 1983. Timber Management: A Quantitative Approach. New York: John Wiley & Sons, p. 333.
- Curtis RO, DeMars DJ, Herman FR. 1974. Which dependent variable in site index-height-age regression? *Forest Science*, **20**(1): 74–87.
- Echeverri RR. 1968. Bases para la formulación de proyectos de reforestación con teca (*Tectona grandis* Lin. F.) en Colombia. Trabajo de Grado, Ingeniería Forestal. Medellín: Universidad Nacional de Colombia Sede, p. 50.
- Fang Z, Bailey RL. 2001. Nonlinear mixed effects modelling for slash pine dominant height growth following intensive silvicultural treatments. *Forest Science*, **47**(3): 287–300.

- Fang Z, Bailey RL, Shiver BD. 2001. A multivariate simultaneous prediction system for stand growth and yield with fixed and random effects. *Forest Science*, **47**(4): 550–562.
- Gregoire TG. 1987. Generalized error structure for forestry yield models. *Forest Science*, **33**(2): 423–444.
- Henao ID. 1982. Estudio de rendimientos y rentabilidad en una plantación de teca (*Tectona grandis* L.F.) del departamento de Córdoba, Colombia. *Crónica Forestal y del Medio Ambiente*, **2**(1/2): 1–75.
- Holdridge LR. 1982. Ecología basada en zonas de vida. San José, Costa Rica: Instituto Interamericano de Cooperación para la Agricultura, p. 216.
- IGAC, Instituto Geográfico Agustín Codazzi. 1978. Atlas regional del Caribe. Bogotá, Colombia. p.120.
- IGAC, Instituto Geográfico Agustín Codazzi (1989) Atlas básico de Colombia, Bogotá, Colombia. 720 pp.
- Jerez-Rico M, Moret-Barillas AY, Carrero-Gámez AE, Machiavelli RE, Quevedo-Rojas AM. 2011. Curvas de índice de sitio basadas en modelos mixtos para plantaciones de teca (*Tectona grandis* L.F.) en los llanos de Venezuela: site index curves based on mixed models for teak (*Tectona grandis* L.F.) plantations in the Venezuelan plains. *Agrociencia*, **45**: 135–145.
- Keogh RM. 1981. Teca (*Tectona grandis*). Procedencias del Caribe: América Central, Venezuela y Colombia. In: Whitmore JL. (ed). Producción de Madera en los Neotrópicos via Plantaciones, Proc. IUFRO/MAB/U.S. Forest Service Symposium, IUFRO Working Group SI-07-09, Sept. 1980, Inst. Trop For Río Piedras, Puerto Rico, pp. 356–372.
- Keogh RM. 1982. Teak (*Tectona grandis* Linn. f.), provisional site classification chart for the Caribbean, Central America, Venezuela and Colombia. *Forest Ecology and Management*, **4**(2): 143–153.
- Kiviste A, Álvarez JG, Rojo A, Ruiz AD. 2002. Funciones de crecimiento de aplicación en el ámbito forestal. Madrid: Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria, p. 190.
- Lowe RG. 1976. Teak (*Tectona grandis* Linn. F.) thinning experiment in Nigeria. *Commonwealth Forestry Review*, **55**(165): 189–202.
- Malende YH, Temu AB. 1990. Site-index curves and volume growth of teak (*Tectona grandis*) at Mtibwa, Tanzania. *Forest Ecology and Management*, **31**(1/2): 91–99.
- Miller AD. 1969. Provisional yield tables for teak in Trinidad, Trinidad and Tobago, Government Printery, Port of Spain. p. 20.
- Mora FA, Meza V. 2004. Comparación del crecimiento en altura de la Teca (*Tectona grandis*) en Costa Rica con otros trabajos previos y con otras regiones del mundo, Universidad Nacional, Heredia, Costa Rica. Available at: www.una.ac.cr/inis/discusion. [Accessed on 15 September, 2010].
- Nunifu TK, Murchinson HG. 1999. Provisional yield models of teak (*Tectona grandis* Linn. F.) plantations in northern Ghana. *Forest Ecology and Management*, **120**(1–3): 171–178.
- Pérez D, Kanninen M. 2005. Stand growth scenarios for *Tectona grandis* plantations in Costa Rica. *Forest Ecology and Management*, **210**(1–3): 425–441.
- Rodríguez R. 1968. Estudio alternativo de zonas aptas para teca. (Trabajo de Grado Ingeniería Forestal). Universidad Nacional de Colombia sede Medellín. p. 55.
- SAS. 1999. Online Doc version eight, SAS Institute Inc., Cary, NC, USA.
- Schumacher FX. 1939. A new growth curve and its application to timber in yield studies. *Journal of Forestry*, **37**: 819–820.
- Upadhyay A, Eid T, Sanlhayan PL. 2005. Construction of site index equations for even aged stands of *Tectona grandis* (teak) from permanent plots data in India. *Forest Ecology and Management*, **212**: 14–22.
- Vaides E, Ugalde L, Galloway G. 2004. Crecimiento y productividad de teca en plantaciones forestales jóvenes en Guatemala. *Recursos Naturales y Ambiente*, **46–47**: 137–145.
- Vincent LW, Moret AY, Jerez M. 2000. Comparación de algunos regímenes de espesura en plantaciones de teca en el área experimental de la Reserva Forestal de Caparo, Venezuela. *Rev Forest Venez*, **44**(2): 87–95.